# MARKET SIZE, TRADE AND RESISTANCE TO TECHNOLOGY ADOPTION

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Abstract: Why is the adoption of more productive technologies more fiercely resisted in some societies than in others? This paper examines the role of market size and free trade in determining whether firms or workers resist the adoption of more advanced technologies. It puts forth a model whereby the price elasticity of demand for each industry's product is an increasing function of the economy's population size. A more elastic demand lowers the resistance to technology adoption because the drop in the price of the industry's output that follows the adoption of a cost-saving technology is associated with a larger increase in industry's revenue. We demonstrate this mechanism numerically and provide empirical support for this theory.

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## 1 Introduction

Why is it that some societies fail to adopt more productive, readily available technologies? In these societies, either firms never attempt to introduce more productive technologies, or when they do, their efforts are successfully resisted by factor suppliers. This paper examines the role of market size and free trade in determining whether firms will attempt to adopt more productive technologies and whether their factor suppliers will resist technological upgrading.

The paper's hypothesis is that population size and free trade facilitate the adoption of more productive technologies by raising the price elasticity of demand for the firm's product. The higher price elasticity of demand is critical because it implies a larger increase in revenues following the price drop associated with the introduction of a more productive technology. As a result, technology adoptions are more profitable, and the earnings of factor suppliers are less likely to fall. Firms operating in larger markets therefore have a greater incentive to adopt readily available technologies, and their factor suppliers have a lower incentive to resist them.

This is not to say that there are no other factors that prevent firms in poor countries from introducing more productive technologies developed in rich countries. Some technologies, particularly those related to agriculture and mining, may not be suited for the geographic conditions present in other countries. Access to capital markets is clearly another factor that matters. Similarly, an illiterate and unskilled workforce may make it unprofitable for firms to adopt more productive technologies. Still, there are countless historical and contemporary examples of technologies not being adopted in some places, that cannot be attributed to any of the aforementioned factors, and are thus in need of an alternative explanation. This motivates us to explore the role of market size.

To examine the relation between market size, demand elasticity and technology adoption, we use a version of Lancaster's (1979) model of trade in ideal varieties. As shown by Helpman and Krugman (1985) and Hummels and Lugovskyy (2005), this model has the property that the absolute value of the elasticity of demand is an increasing function of the population size. The key for generating this result is that the marginal utility of adding one more variety decreases in the number of varieties available for consumption. As a result, when the economy's size doubles, the number of varieties increases by less than a factor of 2. This contrasts with the Dixit-Stiglitz (1977) approach, where the marginal utility of variety is constant, so that the elasticity of demand is invariant to the size of the economy. Whereas Helpman and Krugman (1985) and Hummels and Lugovskyy (2005) examine how population size and trade affect the price elasticity of demand and the number of varieties produced by an economy, we examine how these same elements affect the incentives of firms to adopt a more productive technology and the incentives of their workers to resist that adoption.

The model consists of a perfectly competitive agricultural sector, a monopolistically competitive industrial sector, and a household sector. Not all households are free to work in all sectors, so that wages may differ across sectors. Firms in the industrial sector have the choice between two technologies, a less productive and a more productive one. Both technologies are freely available, in the sense that no firm-specific investment is required to adopt them. This does not imply that firms (or workers) always prefer the more productive technology, as there will be a cost associated with using the superior technology. We consider two alternative ways of modeling this cost.

A first way in which we model the cost of using the more productive technology is through the loss of monopoly power over the less productive technology. If a firm upgrades its technology, any household is allowed to use the less productive technology to produce the firm's variety. This threat of competitive entry imposes a ceiling on the price an adopting firm can charge for its variety. When the size of the market is small, the elasticity of demand is low, and the pricing constraint leads to negative profits if the firm adopts. Firms therefore prefer to stick to the less productive technology. However, if the market size is large, the elasticity of demand is high, and the pricing constraint no longer leads to negative profits. In that case firms have an incentive to switch to the more productive technology.

The higher elasticity of demand in larger markets is key to understanding the positive relation between market size and technology adoption. The elasticity of demand operates through two channels. First, as the elasticity of demand increases, firms face tougher competition, and the markup they charge goes down. The lower markup implies a smaller price drop imposed by the pricing constraint. Second, as the elasticity of demand increases, a given price drop leads to a greater increase in total revenue. Put differently, in more competitive markets lowering the price translates into a bigger gain in market share.

A second way in which we model the cost of using the more productive technology is to have the more productive technology displace the original industrial workers. The idea is that an adopting firm can freely hire both agricultural and industrial workers. The original industrial workers no longer have a skill advantage when using the more productive technology. This puts downward pressure on their wages, so that they resist adoption. A conflict between firms and workers ensues. Firms are only able to switch to the more productive technology if the profits generated by adoption are enough to compensate their workers for the falling wages. The capacity of doing so depends on the size of the market. In larger markets, the elasticity of demand is greater, and competition is fiercer. The price drop, associated with technology adoption, has a bigger effect on revenues and profits.

The use of Lancaster ideal variety preferences is surely important for generating the results in this paper, but it is not essential. What matters, instead, is the positive relation between market size and the elasticity of demand. Therefore, if we were to use the quasi-linear utility function with a quadratic sub-utility studied by Ottaviano, Tabuchi and Thisse (2002), the results would not change. The Dixit-Stiglitz (1977) construct is, however, insufficient for our purpose. In that framework there is no elasticity effect associated with a larger market size. Certainly, with a Dixit-Stiglitz setup it is still possible to generate positive welfare and productivity effects from an increase in market size. This has been done by a large number of authors in a variety of ways. Most look at scale effects that are due to the existence of some fixed cost to innovation.[1] In our model, there is no such fixed cost, as technologies are freely available.

There is one exception in this literature that looks at the adoption of freely available technologies using the Dixit-Stiglitz construct. Holmes and Schmitz (1998) are able to generate an elasticity effect within that framework. Like us, they show that a larger market size lowers the resistance to process innovations through a change in the elasticity of demand for an industry's product. However, there is a key difference: in their paper only trade related increases in market size work to increase the price elasticity of demand and to lower resistance to process innovations. Contrary to empirical evidence, increases in market size due to population growth have no elasticity effect in their model. The dichotomy in their model is an artifact of the Dixit-Stiglitz structure, as well as a number of special assumptions, such as that technology adoptions occur at the country level, rather than at the firm level. In contrast, in our model both free trade and market size stimulate technology adoption. Moreover, the decision of whether to adopt a new

[1] For example, Rodrigues (2005) obtains this result by assuming increasing returns to specialization. There also numerous examples within the endogenous growth literature, with a so-called scale-effect property, including Romer (1990), Grossman and Helpman (1991), and Aghion and Howitt (1992).

technology is taken by individual firms.

Another related paper is Melitz and Ottaviano (2005), who generate an elasticity effect using the Ottaviano, Tabuchi and Thisse (2004) preferences. As in our work, their model does not predict any dichotomy between the effects of free trade and increasing market size. They do not, however, study technology adoption and resistance. In their model, firms choose to enter a market and then realize their productivity and marginal production costs. Ex-post, low productivity firms choose not to produce. Trade and country size raise average productivity by raising the cut-off level whereby a firm would choose to exit the industry.[2] Though we also emphasize the relation between market size and elasticity, we focus on a model where technology adoption is a decision, rather than the outcome of entry and exit and random assignment. In that respect our model is more similar to Yeaple (2005). However, Yeaple (2005) uses Dixit-Stiglitz preferences, so that the elasticity of demand is not part of the discussion.

The rest of the paper is organized as follows. Section 2 presents empirical support for the mechanism we propose. Section 3 lays out the basic structure of the Lancastarian ideal variety model studied in Hummels and Lugovskyy (2004). Section 4 and 5 then study the choice of technologies under different assumptions. In Section 4, the model assumes there is the possibility of competitive entry; in Section 5, the model assumes the more productive technology displaces the original industrial workers. Section 6 concludes the paper.

## 2 Empirical support

The purpose of this section is to provide empirical support for our theory. The empirical support makes use of aggregate-level, industry-level and firm-level data. Before presenting this evidence, however, it is instructive to recall those features and predictions of our model that in their entirety set it apart from the rest of the literature. Our work has vertical innovations and resistance to those innovations; our work is based on a mechanism whereby larger market size works to increase the price elasticity of demand; and our work predicts that both population size and free trade work to eliminate resistance.

[2]This is essentially the mechanism at hand in Syverson (2004). However, his model does not imply an elasticity effect. Instead, it follows Salop (1979) and assumes consumers have an inelastic demand for a single unit of the economy's output.

*Process innovations and resistance*

Resistance to the introduction of superior technologies is a well-documented and very old phenomenon.[3] In the middle ages, the guilds were notorious for blocking the introduction of new production processes or work practices. Perhaps, no instance of resistance is more famous than the Luddites who in 1811 and 1812 blocked the attempts of mill owners to introduce labor saving machines through violence. These same tactics are still in use today, as is evident in a case documented by Fox and Heller (2000) for a large paper mill in Karelia, Russia.

In both examples the fixed or sunk costs with making these changes cannot have been prohibitively large. Otherwise, the plant owners or their managers would not have attempted to introduce these new technologies in the first place. Indeed, there are many instances where an innovation requires no new expenditure, and yet is not adopted. Wolcott (1994), for example, documents the huge number of strikes by Indian textile workers to stop plans by management to introduce changes in work rules. These innovations most often were not associated with the purchase of new machines and equipment, but rather with reorganizations and reassignments of tasks in the mills. Klebnikov and Waxler (1996), for another example, document the case of the Volga Paper Company in Russia, in which huge crates placed in a remote part of the factory containing $100 million in new Austrian-made equipment were left unopened.

*Elasticity of demand and market size*

As explained in the survey by Tybout (2003), a number of theories, many of which belong to the new trade literature, argue that when trade liberalization increases, the price elasticity of demand should rise. Considerable empirical work examining this relation exists. Most studies focus on the effect of trade liberalization on markups, as those theories imply that markups are a decreasing function of the elasticity of demand.[4] Ample empirical evidence, based on plant-level data, supports this relation (Tybout, 2003).

However, these studies do not directly address the impact of a larger market on the elasticity of demand. In our theory, the positive effect of trade on the elasticity has to do with an increase in the size of the market. Campbell and Hopenhayn (2005) provide evidence of the retail industry

[3] Mokyr (1991) provides a comprehensive history of resistance to technological change in the world.

[4] As price and marginal cost data are typically unavailable, this literature uses a variety of methods to infer mark-ups (see Tybout, 2003).

across 225 U.S. cities, consistent with larger markets having lower markups and higher demand elasticities. Another paper that directly estimates the relation between market size and the price elasticity of demand is Barron, Umbeck, and Waddell (2002). These authors use gasoline price and quantity data from individual gas stations in Southern California. They find that the larger Los Angeles market is characterized by lower prices and more elastic demand than the smaller San Diego market.

*Population size, free trade and resistance*

Here we provide aggregate and industry-level evidence consistent with market size and free trade having a positive effect on economic performance. Much of the empirical literature concludes that greater openness is associated with faster growth in per capita output or GDP (see, e.g., Sachs and Warner, 1995, Edwards, 1998, Wacziarg and Welch, 2003, and Alcalá and Ciccone, 2004).[5] Of particular interest is Alesina, Spaloare and Wacziarg (2000), who find that a small population lowers a country's economic performance only if the country is closed. In other words, trade provides a way to compensate for small domestic size. At the industry-level, there is the study of the ready-mix concrete industry by Syverson (2004) in the United States. Using data from the Census of Manufacturers for a variety of years, he shows that average productivity in ready-mix concrete is higher in larger geographical markets.

Our theory argues that larger markets and trade lead to better performance because it breaks down the resistance to technology adoption. Examples where a group that formerly resisted the adoption of a new technology willingly ended their resistance and embraced the technology following an increase in its customer base are not well-documented. One case involves scribbling machines in late 18th century England. According to Randall (1991), the introduction of those machines in the woolen industry in the West of England in 1791 was met by fierce resistance by workers who feared it would lead to their unemployment. Through physical violence and intimidation against the mill owners, the workers blocked the introduction of the scribblers. This resistance continued until the trade boom in 1795. Only after workers could not meet the demand for their mill's product, did they agree to allow mill owners to introduce these machines.

Individually, none of the facts that we document above set our theory apart from alternative

[5] See, nonetheless, the critical review of Rodrik and Rodríguez (2000).

theories and papers. However, taken together, they represent a strong case for the mechanism we propose in this paper. Ours is the only theory that can account for all of this evidence.

## 3 The model economy

We demonstrate the mechanism at hand using Lancaster's ideal variety model as described in Hummels and Lugovskyy (2005), Helpman and Krugman (1985), and Lancaster (1979). The model is static and consists of three sectors: an agricultural sector, an industrial sector, and a household sector. The agricultural sector is competitive and produces a homogeneous good, which serves as the economy's numéraire, using labor as its only input. The industrial sector also uses labor as its only input, but in contrast is monopolistically competitive and produces a differentiated good. The different varieties of the industrial good are located on the unit circle. There is a single technology to produce the agricultural good, but two available technologies to produce each differentiated industrial good. Those two technologies differ in their marginal labor inputs. The household sector is populated by a continuum of households of measure $N$, distributed uniformly around the unit circle. A household's location on the unit circle corresponds to the variety of the differentiated good that it most strongly prefers. Households supply labor to firms in the economy and use the income generated by this activity to buy the agricultural good and the differentiated goods.

In what follows we describe each of these three sectors in detail. In addition, we analyze the utility maximization problem of households, and the profit maximization problem of agricultural firms. For now, we do *not* describe the profit maximization problem of industrial firms, because it depends on the way we introduce the cost of using the more productive technology. We distinguish between two different costs, and discuss those in detail in Section 4 and Section 5.

### *3.1 Household sector*

*Preferences*

A household's utility depends on its consumption of the agricultural good and the differentiated industrial goods. We denote a household's consumption of the agricultural good by $c_a$ and its consumption of the differentiated good $v$ by $c_v$, where $v \in V$. Households are uniformly distributed along the unit circle. Each household's location on the unit circle corresponds to its ideal variety of the industrial good. The farther away a particular variety of the industrial good, $v$, lies from a household's ideal variety, $\tilde{v}$, the lower the utility derived from a unit of consumption of the good. Let $d_{v\tilde{v}}$ denote the shortest arc distance between variety $v$ and the household's ideal variety $\tilde{v}$. Following Hummels and Lugovskyy (2005), the utility of a type $\tilde{v}$ household is

$$U = c_a^{1-\alpha}[u(c_v|v \in V)]^{\alpha} \tag{1}$$

where

$$u(c_v|v \in V) = \max_{v \in V}[\frac{c_v}{1 + d_{v,\tilde{v}}^{\beta}}] \tag{2}$$

In equation (1), $\alpha$ is a parameter that determines the expenditure share of the household between the agricultural good and the differentiated good. In equation (2), the term $1 + d_{v,\tilde{v}}^{\beta}$ is Lancaster's compensation function, i.e., the quantity of variety $v$ that gives the household the same utility as one unit of its ideal variety $\tilde{v}$. The parameter $\beta$ determines how fast utility diminishes with the distance to the ideal variety. As is standard with Lancaster preferences, we restrict the compensation function to be convex, and set $\beta$ to be greater than 1. This implies that compensation rises at an increasing rate as the household moves away from its ideal variety.

*Endowments*

Each household is endowed with one unit of time. Households may differ with respect to how they can use their time endowment, namely, whether they can work in the agricultural sector, the industrial sector with the inferior technology, or the industrial sector with the superior technology. For the purpose at hand, it will be sufficient to distinguish between two types of households, type-1 and type-2. For now, we do not further specify what these two types are, as this will depend on the different assumptions made in Sections 4 and 5. To ensure that a symmetric equilibrium exists, we assume that measure $N_1$ of type-1 households and measure $N_2 = N - N_1$ of type-2 households are each uniformly distributed along the unit circle.

### *3.2 Agricultural sector*

There is a single technology to produce the agricultural good. It uses labor as its only input and exhibits constant returns to scale. Let $Q_a$ denote the quantity of agricultural output and let

$L_a$ denote the labor input. Then

$$Q_a = \Omega_a L_a \tag{3}$$

where $\Omega_a$ is agricultural TFP.

### *3.3 Industrial sector*

Each differentiated good can be produced with either a less productive or a more productive technology. Labor is the only input, and there is a fixed cost $\kappa$ modeled in labor units associated with operating either technology. The two technologies differ solely in their marginal labor inputs. For the inferior technology the marginal labor input is $\phi_1$, whereas for the superior technology it is $\phi_2$, with $\phi_1 > \phi_2$. Let $L_v$ denote the total labor input of a firm producing variety $v$, and let $Q_v$ be the output of such a firm. Then, the output associated with using technology $i = 1, 2$ is

$$Q_v = \phi_i^{-1}[L_v - \kappa] \tag{4}$$

### *3.4 Household utility maximization*

Given that households may differ in the use of their time endowment, they may differ in their incomes. Let $w_1$ denote the wage earned by a household of type 1 and $w_2$ the wage paid to a household of type 2.[6] Cobb-Douglas preferences imply that each household spends a fraction $1-\alpha$ of its income on the agricultural good, and the remaining fraction $\alpha$ on the differentiated goods. That is

$$c_a^i = (1-\alpha)w_i \quad \text{if } i = 1, 2 \tag{5}$$

$$\int_{v \in V} p_v c_v^i = \alpha w_i \quad \text{if } i = 1, 2 \tag{6}$$

The sub-utility function given by equation (2) implies that each household buys only one differentiated good. As such, the quantity of the variety $v'$ purchased by a household satisfies

$$c_{v'} = \alpha w_i / p_{v'} \tag{7}$$

The variety $v'$ that a household located at $\tilde{v}$ on the unit circle consumes is the one that maximizes

$$\frac{\alpha w_i}{p_v(1 + d_{v\tilde{v}}^{\beta})}$$

[6]Free entry into the industrial sector ensures that firms there make zero profits. Thus, the only income of a household is its labor income.

It follows immediately that this household only consumes that variety $v$ which minimizes $p_v(1+d^{\beta}_{v\tilde{v}})$, so that

$$v' = \text{argmin}[p_v(1+d^{\beta}_{v,\tilde{v}})|v \in V]$$

Now that we have derived an individual household's demand, we can determine aggregate household demand for a given variety. The expression of total demand for any variety is independent of the technology used by the firms. For this reason, we can derive the demand for a firm's product before examining its choice of technology. The aggregate demand facing a firm producing variety $v$ depends on the location on the unit circle of its nearest competitor to its left, $s$, and to its right, $z$, as well as on the prices charged by those firms, $p_s$ and $p_z$. If the price of variety $v$ is $p_v$, then the household on the unit circle who is just indifferent between buying variety $v$ and variety $s$ is identified by location $u$, which satisfies

$$p_s(1+d^{\beta}_{su}) = p_v(1+d^{\beta}_{uv})$$

Similarly, the household on the unit circle who is just indifferent between buying variety $v$ and variety $z$ is identified by location $y$, which satisfies

$$p_z(1+d^{\beta}_{yz}) = p_v(1+d^{\beta}_{yv})$$

Given these prices and locations, it follows that the customer base of industry $v$ is the compact set of households with ideal variety located between $u$ and $y$. More specifically, the share of customers served by industry $v$ equals the shortest arc distance between variety $v$ and $u$, $d_{uv}$, plus the shortest arc distance between variety $v$ and $y$, $d_{yv}$.

Household preferences imply that each household spends a fraction $\alpha$ of its total income on a single variety. As type-1 and type-2 households are each uniformly distributed along the unit circle, it follows that total demand for firm $v$'s product is

$$Q_v = \frac{(d_{uv}+d_{yv})\alpha[w_1N_1+w_2N_2]}{p_v}$$

In a symmetric equilibrium, $d_{uv} = d_{yv}$ and $d_{sv} = d_{zv}$. In that case, denote the distance between firm $v$ and the indifferent household by $d'$, the distance between firm $v$ and its nearest competitor to the right (and to the left) by $d$, and the price charged by these competitors by $p$. Then, firm $v$'s total demand is

$$Q_v = \frac{2d'\alpha[w_1N_1+w_2N_2]}{p_v} \tag{8}$$

and the condition that determines the indifferent customer can be re-written as

$$p[1 + (d - d')^{\beta}] = p_v[1 + d'^{\beta}] \tag{9}$$

### *3.5 Agricultural firm equilibrium conditions*

The agricultural sector is competitive. Let $w_a$ denote the wage rate paid to a household working in the agricultural sector. The problem of an agricultural firm is to maximize profits, namely, $\Omega_a L_a - w_a L_a$. The first order necessary condition is

$$w_a = \Omega_a$$

## 4 Loss of monopoly control over the less productive technology

When an industrial firm produces a certain variety, it gets the monopoly right over the technology to produce that variety. It is free to use the less productive or the more productive technology. However, if it opts for the more productive technology, it forfeits the monopoly right over the less productive technology. In that case, any household is free to enter the market, and use the less productive technology, without incurring the fixed cost, to produce the firm's variety. This risk of competitive entry imposes a cost on the adopting firm in the form of a pricing constraint.

Though technology adoption imposes a pricing constraint, it does *not* require a firm-specific fixed investment, which would imply the use of resources — labor or goods — to switch to the more productive technology. Such a resource cost would lead to a scale-economy effect: as a larger economy would allow firms to spread the fixed cost among a larger customer base, it would be more likely to adopt the superior technology. We abstract from this type of adoption cost, because we wish to highlight that it is not needed to generate a positive relation between market size and technology adoption. Our focus is on why technologies which are freely available — and thus do not require any fixed investment to adopt — are sometimes resisted.

To understand the threat of competitive entry, it is important to specify the constraints on the use of the households' time endowment. Type-2 households are the only ones that can be employed by industrial firms, whereas type-1 households are constrained to be laborers in the agricultural sector. However, if any industrial firm switches to the more productive technology, type-1 households are allowed to start producing the firm's variety as self-employed workers, using the less productive technology. To deter competitive entry, an adopting firm will therefore have an incentive to charge a low enough price. This explains why the loss of monopoly control leads to a pricing constraint.

In what follows, we first characterize the relevant problem of industrial sector firms, and then describe the set of necessary conditions for a symmetric equilibrium without technology adoption and with technology adoption. The household utility maximizing conditions and the agricultural firm profit maximizing conditions are the ones derived in Section 3. Next, we examine how the equilibrium properties of the model change as the population increases. This we do via a series of computation. We are particularly interested in understanding how the incentive to switch to the more productive technology depends on the size of the market.

### *4.1 Profit maximization of industrial firms*

A firm chooses its variety and its price, as well as the technology, so as to maximize its profits subject to the demand for its product, taking as given the choices of other firms. In other words, firms behave non-cooperatively. In case a firm uses the more productive technology, it faces the additional constraint that entry will occur by households using the less productive technology if it sets too high a price for its variety. Increasing returns to scale imply that each firm produces a different variety. However, firms in the industrial sector are free to enter and exit, because the fixed cost is only incurred if a firm has positive production. This guarantees profits of all firms must be zero in equilibrium. The zero profit condition effectively pins down the number of varieties produced in the economy.

As is standard, we will focus exclusively on symmetric zero profit Nash equilibria, although other non-symmetric equilibria cannot be excluded. In a symmetric equilibrium, all industrial firms are equally spaced along the unit circle, charge the same price, employ the same number of workers, and use the same technology. In this particular framework, there will be two possible equilibria, one where all industrial firms use the inferior technology, and another where they have all switched to the superior technology.

*The no adoption case*

In the case a firm does not use the superior technology, its profit maximization problem is

$$p_v Q_v - w_x L_v$$

subject to the variety's demand (8) and the production technology (4) with $\phi_i = \phi_1$ and $w_x$ denoting the wage of industrial workers. As in the standard monopoly problem, the profit maximizing price is a mark-up over the marginal unit cost of production $w_x\phi_1$, namely

$$p_v = \frac{w_x \phi_1 \varepsilon}{\varepsilon - 1} \tag{10}$$

In the above equation $\varepsilon$ is the price elasticity of demand for variety $v$. More specifically,

$$\varepsilon = -\frac{\partial Q_v}{\partial p_v}\frac{p_v}{Q_v}$$

Given the variety's demand (8) it is easy to show that

$$1 - \varepsilon = \frac{\partial d'}{\partial p_v}\frac{p_v}{d'} \tag{11}$$

To solve for $\partial d'/\partial p_v$, we differentiate both sides of equation (9) with respect to $p_v$. This yields

$$\frac{\partial d'}{\partial p_v} = \frac{-(1 + d'^{\beta})}{p\beta(d - d')^{\beta-1} + p_v \beta d'^{\beta-1}}$$

Using this result together with equation (11) gives us

$$1 - \varepsilon = \frac{-(1 + d'^{\beta})p_v}{[p\beta(d - d')^{\beta-1} + p_v \beta d'^{\beta-1}]d'}$$

In a symmetric no adoption equilibrium, $p_v = p$ and $d' = d/2$, so that

$$\varepsilon = 1 + \frac{1}{2\beta}(\frac{2}{d})^{\beta} + \frac{1}{2\beta} \tag{12}$$

*The adoption case*

In the case all firms use the superior technology, the profit maximization is subject to an additional constraint. If a firm adopts the superior technology, then any household can use its own labor to produce the same variety with the inferior technology, without having to incur the fixed cost. Type-1 households will have an incentive to do so if the income they could earn from producing variety $v$ with the old technology, $p_v/\phi_1$, is greater than their wages in the agricultural sector, $w_a$. A similar condition applies to type-2 households: they would do the same if $p_v/\phi_1$ is greater than $w_x$. This entry threat of competitive firms puts an effective ceiling on the price the firm using the superior technology can charge, $p_v \leq \min\{w_a\phi_1, w_x\phi_1\}$.

As the maximization problem for a firm is the same except for this additional constraint, the first order necessary conditions are the same as before, with the difference that

$$p_v = \min\{\min\{w_a\phi_1, w_x\phi_1\}, \frac{w_x\phi_2\varepsilon}{\varepsilon - 1}\}$$

### *4.2 Zero industrial profit condition*

The number of varieties in equilibrium is determined by the condition that industrial firms earn zero profits. Profits of a firm using technology $\phi_i$ can be written as $p_v Q_v - w_x(\kappa + Q_v\phi_i)$. In the symmetric equilibrium with no adoption, the zero profit condition is

$$Q_v = \kappa\phi_1^{-1}(\varepsilon - 1)$$

This is derived by substituting the profit maximizing price (10) into the profit equation and setting profits to zero. In the symmetric equilibrium with adoption this condition is

$$Q_v = \begin{cases} w_x\kappa/[\min\{w_a\phi_1, w_x\phi_1\} - w_x\phi_2] & \text{if } p_v = \min\{w_a\phi_1, w_x\phi_1\} \\ \kappa\phi_2^{-1}(\varepsilon - 1) & \text{if } p_v = w_x\phi_2\varepsilon/(\varepsilon - 1) \end{cases}$$

Note that in a symmetric equilibrium the number of varieties is equal to the inverse of the arc distance between neighboring firms on the unit circle. Thus, if $d$ is the distance between any two varieties, then the number of varieties in a symmetric equilibrium is $d^{-1}$.

### *4.3 Symmetric equilibrium with no adoption*

We are now ready to define a *symmetric equilibrium with no adoption.*

Definition 1 *A Symmetric Equilibrium with No Adoption is a vector of prices and allocations* $(w_a^* = w_1, w_x^* = w_2, d^*, \varepsilon^*, L_v^*, Q_v^*, p^*, c_a^{1*}, c_a^{2*})$ *that satisfies*

1. $c_a^i = (1 - \alpha)w_i \quad i = 1, 2$ *(utility maximization of type i household)*
2. $N_1 c_a^1 + N_2 c_a^2 = \Omega_a L_a$ *(agricultural market clears)*

*3.* $w_a = \Omega_a$ *(profit maximization agricultural firms)*

*4.* $L_v/d = N_2$ *(industrial labor market clears)*

*5.* $L_a = N_1$ *(agricultural labor market clears)*

*6.* $\varepsilon = 1 + \frac{1}{2\beta}(\frac{2}{d})^\beta + \frac{1}{2\beta}$ *(definition of elasticity)*

*7.* $p = \frac{w_x \phi_1 \varepsilon}{\varepsilon - 1}$ *(profit maximization of industrial firm)*

*8.* $Q_v = \kappa \phi_1^{-1}(\varepsilon - 1)$ *(zero profit condition)*

*9.* $Q_v = \frac{d\alpha[w_a N_1 + w_x N_2]}{p}$ *(demand for variety v)*

*10.* $Q_v = \phi_1^{-1}(L_v - \kappa)$ *(supply of variety v)*

*11. No firm finds it profitable to adopt the superior technology. Namely,* $\hat{\pi} < 0$ *where* $\hat{\pi}$ *equals*

$$
\begin{aligned}
\arg \max_{d',\varepsilon,p_v,Q_v} \quad & \{p_v Q_v - w_x^*[Q_v\phi_2 + \kappa]\} \\
s.t. \quad & Q_v = \frac{2d'\alpha[w_a^* N_1 + w_x^* N_2]}{p_v} \\
& p_v^*[1 + (d^* - d')^\beta] = p_v[1 + d'^\beta] \\
& p_v \leq \min\{w_a^*\phi_1, w_x^*\phi_1\} \\
& \varepsilon = 1 + \frac{(1 + d'^\beta)p_v}{[p_v^*\beta(d^* - d')^{\beta-1} + p_v\beta d'^{\beta-1}]d'}
\end{aligned}
$$

The last condition in the above definition says that no firm should have an incentive to deviate and adopt the superior technology. Put differently, no firm should make positive profits by switching to the superior technology. If not, this would not be a Nash equilibrium. The critical component of this last condition is the pricing constraint $p_v \leq \min\{w_a^*\phi_1, w_x^*\phi_1\}$. In the absence of the pricing constraint, firms would *always* want to deviate, given there is no firm-specific investment required to adopt the more productive technology.

We now look at the incentive to deviate in further detail. If a firm producing variety $v$ adopts the new technology, its profit maximizing price $p_v$ changes. This, in turn, affects its customer base. If $d^*$ is the equilibrium distance between two neighboring firms, then a share $d'$ will buy from the deviating firm, and a share $d^* - d'$ from its neighbor. Given that each firm has two neighbors, the total customer share of the deviating firm is $2d'$. The household located at a distance $d'$ from the deviating firm is indifferent between buying from the deviating firm or from its neighbor:

$$p^*(1+(d^*-d')^\beta) = p_v(1+d'^\beta) \tag{13}$$

By implicit differentiation, we find:

$$\frac{\partial d'}{\partial p_v} = -\frac{1+d'^\beta}{p^*\beta(d^*-d')^{\beta-1}+p_v\beta d'^{\beta-1}} \tag{14}$$

Demand for the deviating firm's goods can be written as:

$$Q_v = \frac{2d'\alpha[w_a^*N_1 + w_x^*N_2]}{p_v} \tag{15}$$

Differentiating $Q_v$ in (15) with respect to $p_v$, and using expression (14) allows us to derive an expression for the deviating firm's elasticity:

$$\varepsilon_v = 1 + \frac{(1+d'^\beta)p_v}{[p_v^*\beta(d^*-d')^{\beta-1}+p_v\beta d'^{\beta-1}]d'} \tag{16}$$

In the absence of any constraint, profit maximization would require the deviating firm to charge the price:

$$p_v = \frac{\phi_2 w_x^* \varepsilon_v}{\varepsilon_v - 1} \tag{17}$$

However, as argued before, in reality the firm faces a constraint: it will never want to charge a price that gives other households an incentive to start using the firm's old technology. As a result, $p_v$ can never be greater than $\min\{w_a^*\phi_1, w_x^*\phi_1\}$. The price set by the deviating firm is therefore:

$$p_v = \begin{cases} \frac{\phi_2 w_x^* \varepsilon_v}{\varepsilon_v - 1} & \text{if } \frac{\phi_2 w_x^* \varepsilon_v}{\varepsilon_v - 1} \leq \min\{w_a^*\phi_1, w_x^*\phi_1\} \\ \min\{w_a^*\phi_1, w_x^*\phi_1\} & \text{else} \end{cases} \tag{18}$$

The deviating firm's profit can then be written as:

$$\pi_v = p_v Q_v - w_x^*(\kappa + \phi_2 Q_v) \tag{19}$$

where $Q_v$ can be computed from equations (13) and (15) and $p_v$ is given by (18). The definition of a *symmetric equilibrium with no adoption* requires that the deviating firm's profit is negative.

### *4.4 Symmetric equilibrium with adoption*

By analogy, a *symmetric equilibrium with adoption* can now be defined as:

Definition 2 *A Symmetric Equilibrium with Adoption is a vector of prices and allocations* ($w_a^* = w_1, w_x^* = w_2, d^*, \varepsilon^*, L_v^*, Q_v^*, p^*, c_a^{1*}, c_a^{2*}$) *that satisfies*

1. $c_a^i = (1-\alpha)w_i \quad i = 1, 2$ *(utility maximization of type i household)*

2. $N_1 c_a^1 + N_2 c_a^2 = \Omega_a L_a$ *(agricultural market clears)*

3. $w_a = w_1 = \Omega_a$ *(profit maximization agricultural firms)*

4. $L_v/d = N_2$ *(industrial labor market clears)*

5. $L_a = N_1$ *(agricultural labor market clears)*

6. $\varepsilon = 1 + \frac{1}{2\beta}(\frac{2}{\tau})^\beta + \frac{1}{2\beta}$ *(definition of elasticity)*

7. $p_v = \min\{\min\{w_a\phi_1, w_x\phi_1\}, \frac{w_x\phi_2\varepsilon}{\varepsilon-1}\}$ *(profit maximization of industrial firm)*

8. $Q_v = \begin{cases} w_x\kappa/[\min\{w_a\phi_1, w_x\phi_1\} - w_x\phi_2] & \text{if } p_v = \min\{w_a\phi_1, w_x\phi_1\} \\ \kappa(\varepsilon-1)/\phi_2 & \text{if } p_v = w_x\phi_2\varepsilon/(\varepsilon-1) \end{cases}$

   *(zero profit condition)*

9. $Q_v = \frac{d\alpha[w_a N_a + w_x N_x]}{p}$ *(demand for variety v)*

10. $Q_v = \phi_2^{-1}(L_v - \kappa)$ *(supply of variety v)*

11. *No firm finds it profitable to use the inferior technology. Namely,* $\hat{\pi} < 0$ *where* $\hat{\pi}$ *equals*

$$\begin{aligned} \arg \max_{d',\varepsilon,p_v,Q_v} \quad & \{p_v Q_v - w_x^*(\kappa + Q_v\phi_1)\} \\ s.t. \quad & Q_v = \frac{2d'\alpha[w_a^* N_1 + w_x^* N_2]}{p_v} \\ & p^*[1 + (d^* - d')^\beta] = p_v[1 + d'^\beta] \\ & \varepsilon = 1 + \frac{(1 + d'^\beta)p_v}{[p_v^*\beta(d^* - d')^{\beta-1} + p_v\beta d'^{\beta-1}]d'} \end{aligned}$$

To be a Nash equilibrium, no firm should have an incentive to go back to the inferior technology. This is the meaning of the last condition in the above definition. It is important to note that by deviating, we assume a firm regains monopoly control over the use of the inferior technology. No self-employed household in this case can use its own labor to produce the deviating industry's output using the inferior technology. Effectively, by deviating a firm is trading off a higher marginal cost with eliminating the pricing constraint.

### 4.5 Numerical experiments

In this section we examine how the decision of industrial firms to use the more productive technology depends on the size of the economy's population. To do so, we first compute the prices and allocations that satisfy all but the no deviation condition of the *symmetric equilibrium with adoption* and the prices and allocations that satisfy all but the no deviation condition of the *symmetric equilibrium with no adoption.* We do this for a given population and parametrization of the model. We then check if the no-deviation condition for each symmetric equilibrium is satisfied for the respective candidate set of prices and allocations. If it is, then we conclude that such a symmetric equilibrium exists. We then change the population size, and repeat these steps.

There are two main findings. First, for smaller population size economies, the no deviating condition for a *symmetric equilibrium with no adoption* is satisfied, and thus such an equilibrium exists. However, as the population size increases beyond some level, the no deviation condition is violated. When the economy reaches that threshold, firms switch to the more productive technology. Second, the *symmetric equilibrium with adoption* only exists if the population size is large enough. For smaller economies the no deviating condition of the equilibrium with adoption is violated. In other words, for smaller size economies, the only symmetric equilibrium is the one that uses the less productive technology, whereas for larger size economies, the only symmetric equilibrium is the one that uses the more productive technology.

The positive relation between market size and demand elasticity is key to understanding why larger markets stimulate the adoption of more productive technologies. That elasticity of demand is increasing in population is evident from the following differentiation:[7]

$$\frac{d\varepsilon}{dN_2} = \frac{(2/\kappa)^{\beta}\beta N_2^{\beta-1}}{2\beta(\beta+1)\varepsilon^{\beta} - (2\beta+1)\beta\varepsilon^{\beta-1}} \tag{20}$$

Since $\varepsilon > 1$, this expression is positive, so that an increase in $N_2$ leads to a greater elasticity of demand.

There are two reasons why the low elasticity of demand in small markets has a negative effect on technology adoption. First, when the elasticity is low, competition is weak, and the pre-adoption markup (and price) is high. In that case, the pricing constraint, required to deter competitive entry, imposes a relatively large price drop if a firm decides to adopt. As a result,

[7] By an increase in market size, we refer to a proportional increase in the measures of $N$, $N_1$ and $N_2$.

profits from adopting are more likely to be negative. Second, when the elasticity is low, a given price drop leads to a smaller increase in total revenues. In an environment with relatively weak competition, lower prices do not lead to much gain in market share. These two forces explain why in small sized markets the entry constraint imposes a large cost on the adopting firm, enough so that profits are negative. As the market size increases, the elasticity of demand goes up, and the entry constraint imposes a smaller cost on the adopting firm. Eventually, when the market size becomes sufficiently large, firms switch to the more productive technology, as the pricing constraint does no longer prevent them from making positive profits.

We now report the findings for one parametrization of the model. The parameter values, which are reported in Table 1, were not chosen within the framework of some calibration exercise. Rather, they were chosen with the sole purpose of illustrating the mechanism at hand in the clearest possible way. The 'nice' feature of this experiment is that for all population sizes there exists a symmetric equilibrium. In particular, there exists a population size, $N^* = 116$, such that for $N < N^*$ only the *symmetric equilibrium with no adoption* exists and for $N > N^*$ only the *symmetric equilibrium with adoption* exists. Thus, for sufficiently small economies, the only equilibrium is one with no adoption. For sufficiently large economies, the only equilibrium is one with adoption.

Table 1: Parameter values (first experiment)

| | |
|---|---|
| $\beta = 1.05$ | $\alpha = .60$ |
| $\kappa = .70$ | $\Omega_a = 1.0$ |
| $N_1 = .4N$ | $N_2 = .6N$ |
| $\phi_1 = .1079$ | $\phi_2 = .103$ |

To provide a more complete picture of the properties of the model, Table 2 reports for different levels of population the distance between varieties, the elasticity of demand, the price of the industrial goods, the ratio of industrial to agricultural wages, and the average real wage. Note that the average real wage refers to the indirect utility of a household with an average wage $(w_1N_1 + w_2N_2)/N$ and located at an average distance $d/4$ from its ideal variety:

$$\frac{w_1N_1 + w_2N_2}{N}(1-\mu)^{1-\mu}(\frac{\mu}{p(1+(d/4)^{\beta})})^{\mu}$$

To better understand the effect of technology adoption, the real wage has been normalized to 1 for the largest economy that does *not* adopt the more productive technology.

Table 2: Symmetric equilibrium properties

| $N$ | $d$ | $\varepsilon$ | $p_v$ | $w_x/w_a$ | Real wages |
|---|---|---|---|---|---|
| *Symmetric equilibrium with no adoption* | | | | | |
| 25 | .259 | 5.5 | .1316 | 1.0 | .921 |
| 75 | .142 | 9.1 | .1212 | 1.0 | .983 |
| *Symmetric equilibrium with adoption (binding)* | | | | | |
| 125 | .206 | 6.7 | .1079 | 1.0 | 1.045 |
| 175 | .147 | 8.9 | .1079 | 1.0 | 1.053 |
| 225 | .114 | 11.1 | .1079 | 1.0 | 1.058 |
| 275 | .093 | 13.4 | .1079 | 1.0 | 1.060 |
| 325 | .079 | 15.6 | .1079 | 1.0 | 1.062 |
| 375 | .069 | 17.9 | .1079 | 1.0 | 1.064 |
| 425 | .060 | 20.2 | .1079 | 1.0 | 1.065 |
| 475 | .055 | 22.3 | .1078 | 1.0 | 1.066 |
| *Symmetric equilibrium with adoption (nonbinding)* | | | | | |
| 525 | .052 | 23.4 | .1076 | 1.0 | 1.068 |
| 575 | .050 | 24.5 | .1074 | 1.0 | 1.069 |
| 625 | .048 | 25.5 | .1072 | 1.0 | 1.071 |
| 675 | .046 | 26.5 | .1070 | 1.0 | 1.072 |
| 725 | .044 | 27.5 | .1069 | 1.0 | 1.073 |
| 775 | .043 | 28.4 | .1068 | 1.0 | 1.074 |
| 825 | .041 | 29.3 | .1066 | 1.0 | 1.075 |
| 875 | .040 | 30.2 | .1065 | 1.0 | 1.076 |
| 925 | .039 | 31.1 | .1064 | 1.0 | 1.077 |
| 975 | .038 | 31.9 | .1063 | 1.0 | 1.077 |

Table 2 is divided into three parts. For small levels of population, $N \leq 75$, all firms use the inferior technology. For intermediate levels of population, $125 \leq N \leq 425$, all firms use the superior technology, but the price ceiling to keep other households from entering the market is binding. For large levels of population, $N \geq 475$, all firms continue to use the superior technology, but the price ceiling ceases to be binding. As the size of the market increases, the price of the industrial good falls, the elasticity of demand rises, and the average real wage goes up. Those results depend partly on the market size becoming larger; however, adopting the superior technology reinforces them.

Even if there is no technology adoption, in Lancaster type models larger markets have two positive effects. They increase average firm size. This leads to more efficient production, lower prices and higher real wages. Larger markets also generate more varieties. This allows the average household to be located closer to its ideal variety. This contributes to a further rise in average real wages. Note that the relative wage of industrial workers is constant. This is an artifact of the parameter values and the result that in a symmetric equilibrium $w_x = \alpha N_1/((1-\alpha)N_2)$. One other result draws attention. When the population increases from 75 to 125, and firms switch to the superior technology, there is a drop in the elasticity and in the number of varieties produced. This may seem odd. However, this happens because firms cannot sell above the price ceiling. For economies just above the threshold of $N^* = 116$, this implies a substantial price drop, which explains why certain firms are forced out of the market.

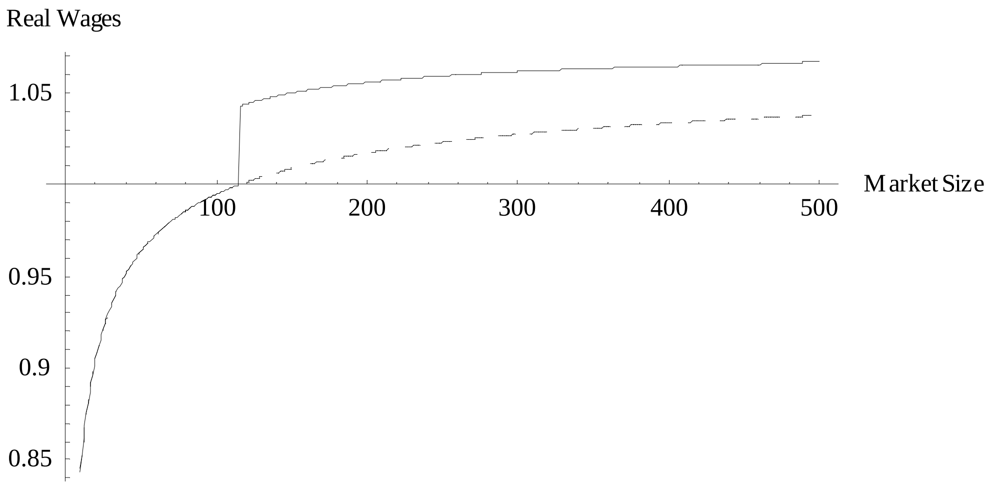


Figure 1: Effect of technology adoption on real wages. The full curve takes into account the effect of technology adoption, whereas the dashed curve does not.

The adoption of the more productive technology in larger economies reinforces the positive effects of market size on real wages. To isolate the effect of switching to the more productive technology, Figure 1 compares the average real wage from Table 2 (full curve) to what the average real wage would be in the absence of technology adoption (dashed curve). Until $N^* = 116$ the two curves coincide, because below that threshold firms do not have an incentive to switch to the more advanced technology. Once we reach the threshold though, firms adopt the superior technology, and the utility jumps up. The difference between the two curves represents the contribution of technology upgrading to the average real wage.

To see how the incentive to adopt the more productive technology depends on the market size, consider the following experiment. Assume that an adopting firm redistributes all profits (or losses) to its original workers. Their real wages fall or rise, depending on whether adoption is profitable or not. Figure 2 plots the relative change in those real wages in function of market size. Consistent with what we said before, for a population size $N^* < 116$, adoption would imply losses, so real wages would drop. In that case, no firm would wish to switch to the more productive technology. Above that threshold, however, adoption leads to profits, and thus higher real wages. This positive effect is increasing in the size of the market.

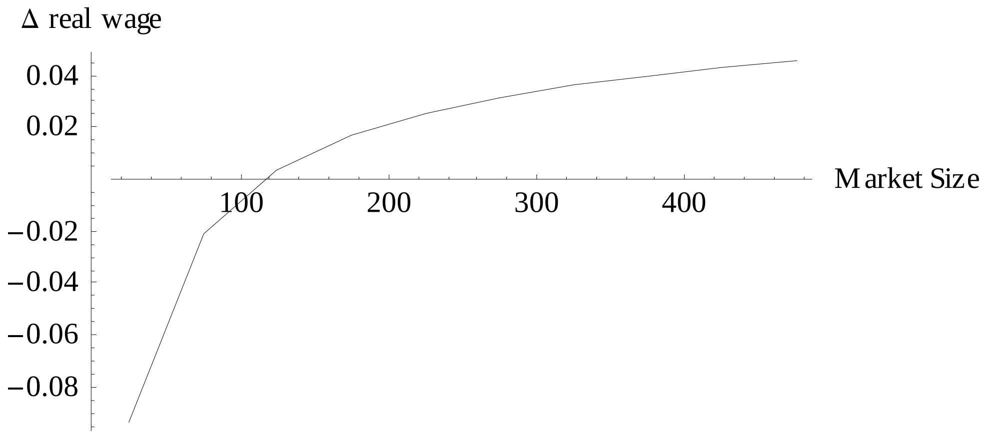


Figure 2: Relative effect of technology adoption on the real wages of workers in an adopting firm.

One possible criticism to this model is that workers never resist technology adoption. A firm will only choose to switch to the more productive technology if it does not make any losses after paying its workers at least the going market wage. Therefore, although firms may decide to adopt or not adopt the more advanced technology, they do not face resistance on the part of workers. As resistance by factor suppliers is a well documented phenomenon, in the next section we modify the model to allow for antagonism between workers and firms.

## 5 Resistance to technology adoption

In this version of the model firms no longer lose their monopoly power over the less productive technology when switching to the more productive one. As a result, the pricing constraint disappears, implying that industrial firms now *always* have an incentive to adopt the more productive technology, regardless of the economy's population size.

Although firms always will prefer the more productive technology, their workers may resist. When upgrading its technology, we assume a firm can freely hire type-1 as well as type-2 households, who are both equally adept at using the more productive technology. The underlying assumption is that type-2 households are skilled in the original (less productive) technology, but have no advantage in operating the new (more productive) technology. By switching to the more advanced technology, type-2 households lose their privileged position. Assuming wages are lower in agriculture than in industry, those households stand to lose in the form of falling wages if their firm decides to adopt the more productive technology.

To try to break workers' resistance, a firm that wishes to switch to the more productive technology redistributes part of the profits from adoption to its original workers. However, bargaining over how to split up the cake is costly. We assume an exogenous share $\gamma$ of the profits is lost in the process. As a result, workers receive a maximum share $1-\gamma$ of the adopting firm's profits.[8] If that share is enough to compensate the original workers for their falling wages, resistance breaks down, and adoption occurs. If not, firms continue to use the less productive technology.

In the analysis that follows, we limit ourselves to studying the incentive of firms to deviate from the *symmetric equilibrium with no adoption*.[9] After defining the equilibrium with no adoption, we use numerical examples to illustrate how adoption depends on the size of the market.

[8] One could think of $\gamma$ as representing union dues. For a large number of unions in the United States membership dues are set as a certain percentage of a worker's earnings.

[9] Since the focus is on the adoption of more advanced technologies, we refrain from discussing the incentive of firms to deviate from the *symmetric equilibrium with adoption*. In fact, it would not be entirely obvious how to determine the no-deviation condition in that case. Adopting firms typically employ both type-1 and type-2 households. Since their respective incentives to deviate are different, the no-deviation condition would depend on which households have the power within the firm.

### 5.1 Symmetric equilibrium with no adoption

If a firm did not face resistance from workers, it would always adopt the more productive technology. The reason is two-fold: the technology is better, $\phi_2 < \phi_1$, and the firm can hire workers at the agricultural wage rate, which we assume to be lower.[10] The firm's workers will only give up resistance if the share $1-\gamma$ of the profits generated by adoption is enough to at least maintain their wages

$$w_a + \pi(1-\gamma)/L_v \geq w_x$$

where $L_v$ refers to the original number of workers in the firm, and $\pi$ is the profit of the deviating firm. Note that $w_a = \Omega_a$ and $w_x = \alpha N_1/((1-\alpha)N_2)$ are the respective wages that would prevail in a *symmetric equilibrium with no adoption.*

Given the assumptions of the model, the definition of the *symmetric equilibrium with no adoption* is as follows:

Definition 3 *A Symmetric Equilibrium with No Adoption (with workers' resistance) is a vector of prices and allocations* $(w_a^*, w_x^*, d^*, \varepsilon^*, L_v^*, Q_v^*, p^*, c_a^{1*}, c_a^{2*})$ *that satisfies Conditions 1-10 of Definition 1 and*

*11'. Workers find it profitable to block the adoption of the superior technology. Namely,* $w_a^* + \hat{\pi}(1-\gamma)/L_v^* \geq w_x^*$*, where* $\hat{\pi}$ *equals*

$$\begin{aligned} \arg \max_{d',\varepsilon,p_v,Q_v} \quad & \{p_v Q_v - w_a^*[Q_v\phi_2 + \kappa]\} \\ s.t. \quad & Q_v = \frac{2d'\alpha[w_a^* N_1^+ w_x^* N_2]}{p_v} \\ & p_v^*[1 + (d^* - d')^\beta] = p_v[1 + d'^\beta] \\ & \varepsilon = 1 + \frac{(1 + d'^\beta)p_v}{[p_v^*\beta(d^* - d')^{\beta-1} + p_v\beta d'^{\beta-1}]d'} \end{aligned}$$

This last condition says that the symmetric equilibrium with no adoption is a Nash equilibrium if no firm has an incentive to deviate and switch to the more productive technology. For this to be the case, the profits generated by adoption, *net* of a share $\gamma$, should not be enough to maintain the earnings of the original workers.

[10]This is so as long as the parameters of the model satisfy $w_x = \alpha N_1/((1-\alpha)N_2) > \Omega_a = w_a$.

## *5.2 Numerical Experiments*

In this section we examine how market size affects the incentives of workers to resist the adoption of the more productive technology. For a given parametrization we compute the prices and allocations that satisfy all but the no-deviation condition of the *symmetric equilibrium with no adoption*. We then determine whether a particular firm has the incentive to deviate. If no firm chooses to deviate, we conclude that the *symmetric equilibrium with no adoption* exists. For such an equilibrium to exist, workers must resist technology adoption. We then analyze how resistance depends on the size of the economy by varying the population, holding the fraction of type-1 and type-2 households in the population constant.

We now report the findings for one parametrization of the model. As before, the parameter values were not chosen within the framework of some calibration exercise. Their sole purpose is to illustrate the mechanism at hand. Table 3 gives the parameter values used.

Table 3: Parameter values (second experiment)

| | |
|---|---|
| $\beta = 1.01$ | $\alpha = .615$ |
| $\kappa = .25$ | $\Omega_a = 1.0$ |
| $N_1 = .4N$ | $N_2 = .6N$ |
| $\phi_1 = .101$ | $\phi_2 = .1$ |
| $\gamma = .25$ | |

Figure 3 represents the change in the real wage of the original workers if a firm adopts the new technology. As can be seen, if the population size is below $N^* = 33$, deviating and adopting the more productive technology would lead to a drop in the original workers' earnings. Therefore, below that threshold, workers resist adoption, and the *symmetric equilibrium with no adoption* exists. Once the population size rises above that cutoff, the original workers gain from technology adoption. As a result, their resistance breaks down, and firms switch to the more productive technology.

Here again, the positive relation between market size and elasticity of demand is key to understanding why larger economies are more likely to adopt the superior technology. To see this, Table 4 reports a number of relevant statistics in function of the size of the population. From

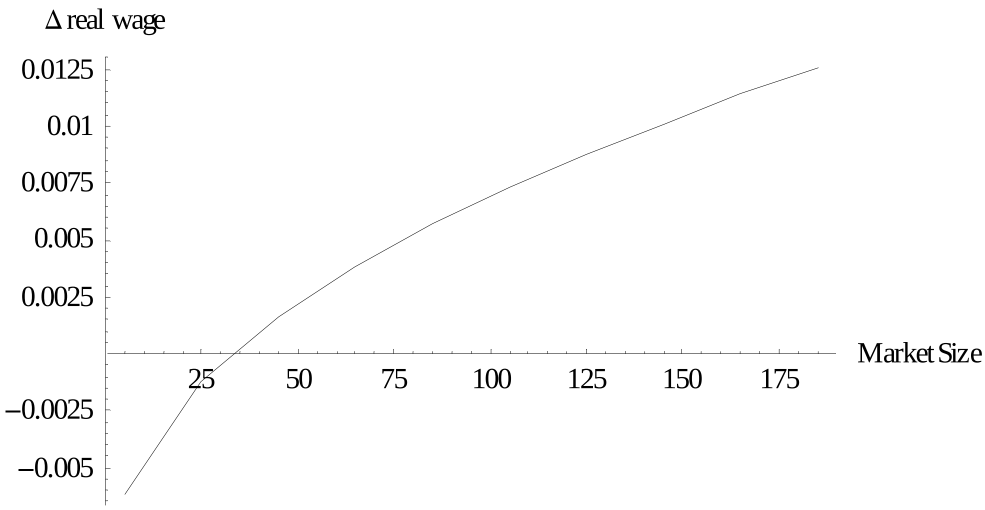


Figure 3: Technology adoption: effect on real wages of original workers

the second column we see that as the size of the market increases, the elasticity of demand goes up. Neighboring varieties become closer substitutes. This means that for a given price drop,[11] output (and total revenue) go up by more, translating into greater profits. This can be seen in column 4, which reports the profits of an adopting firm per original worker. Although profits are always positive, they may not be enough to compensate the original workers for their falling wages. Indeed, because adopting firms can now hire type-1 households, earnings of the original workers drop. For generated profits to be able to compensate those workers, the market size needs to be large enough. This is reflected in column 3, which reports the proportional change in the real earnings of the original workers. Once the market size reaches the threshold $N^* = 33$, firms are able to buy out workers, and will find it profitable to adopt the more productive technology.

We emphasize that there is nothing special about this particular parametrization. We experimented with a number of other parametrizations and found qualitatively the same results. Note, however, that it is important for $\gamma$ to be strictly positive. The reason is straightforward. Take a firm that uses the less productive technology, and makes zero profits in equilibrium. If it were to pay its workers at the lower agricultural wage and maintain all other choice variables constant, profits per worker would exactly be equal to the difference between the industrial and the agricultural wage. If now that same firm were to use the more productive (and thus less costly) technology and maintain the other choice variables constant, its profits per worker would exceed

[11] As can be seen from column 5, the optimal price drop of a deviating firm does not vary much with market size.

Table 4: Symmetric equilibrium properties

| Population $N$ | Elasticity $\varepsilon$ | Change in real wages | Profits per worker | Change in industrial price |
|---|---|---|---|---|
| *Symmetric equilibrium with no adoption* | | | | |
| 5 | 4.3 | -0.0062 | 0.058 | -0.041 |
| 25 | 8.60 | -0.0012 | 0.064 | -0.038 |
| *Deviation and adoption of more productive technology* | | | | |
| 45 | 11.27 | 0.0016 | 0.067 | -0.038 |
| 65 | 13.40 | 0.0038 | 0.069 | -0.037 |
| 85 | 15.21 | 0.0057 | 0.071 | -0.037 |
| 105 | 16.83 | 0.0073 | 0.073 | -0.037 |
| 125 | 18.30 | 0.0088 | 0.074 | -0.037 |
| 145 | 19.66 | 0.0101 | 0.076 | -0.037 |
| 165 | 20.93 | 0.0114 | 0.077 | -0.037 |
| 185 | 22.12 | 0.0126 | 0.078 | -0.037 |
| 205 | 23.25 | 0.0137 | 0.080 | -0.037 |

the difference between the industrial and the agricultural wage. Therefore, if $\gamma = 0$, all profits would be redistributed, workers' earnings would exceed the original industrial wage, and there would never be any resistance to technology adoption. Although this implies that for workers to oppose more productive technologies $\gamma$ should be strictly positive, its value need not be large in any sense. Parameters can be chosen in such a way for resistance to arise for values of $\gamma$ of, say, 0.02, consistent with the kind of union dues paid by some workers in the United States.

## 6 Concluding remarks

This paper has explored how the elasticity of demand in larger markets may be key in understanding why free trade and market size stimulates technology adoption. If the elasticity of demand is high, the drop in the price, following the adoption of a more productive technology, translates into a substantial increase in revenues and profits. This makes it more likely for firms to upgrade their technology. Likewise, in larger markets workers are less likely to resist adoption.

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